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Nuclear-Electromagnetic Cascade Development Study
(Ionization Spectrometer Development)

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A B S T R A C T

This is a proposal for use of a low intensity, external proton beam from the 200 GeV accelerator to study properties of the nuclear-electromagnetic cascade in ionization spectrometers. This work will be carried out primarily for a high energy (10^{10}-10^{14} eV) cosmic ray experiment to be carried on the High Energy Astronomical Observatory (HEAO). The results will be of applicability to all users of ionization spectrometers, however. The main object of the study will be the investigation of the longitudinal and lateral development of nuclear electromagnetic cascades in various dense materials. This information will be important for the design of the ionization spectrometer to be used for the satellite experiment. This information will also be invaluable for interpretation of the spectrometer data obtained during the satellite flights. The measurements will be used to improve an existing Monte Carlo model of the nuclear-electromagnetic cascade. The improved model will be used for the HEAO spectrometer as well as design studies of other ionization spectrometers. This model will also be used for the extrapolation to much higher energies of spectrometer response determined at comparatively low accelerator energies. Another purpose of the experiment is to test the use of plastic scintillator wedges for determining the lateral position of cascades in dense materials. Byproducts of this study will be the determination (as a function of primary energy) of the following properties of individual proton collisions with various target nuclei: 1) the fraction K_{π^o} of the primary energy going into neutral pions, 2) the energy going into disintegration of the target nucleus, and 3) the inelastic cross section. It is estimated that 400 hrs or more of beam time will be required for this work.

This proposal is for the first use of the 200 GeV accelerator for work connected with an ionization spectrometer development needed for an experiment in the High Energy Astronomical Observatory (HEAO). A general proposal for this work has been submitted to NAL by T. Bowen on behalf of the collaborators in this satellite experiment. This general proposal is entitled "Ionization Spectrometer Development and Calibration", and dated June 15, 1970. A copy is attached.

The goals of this first ionization spectrometer work at the accelerator for HEAO are as follows:

1. To determine the properties of ionization spectrometers with various absorber configurations.
2. To measure certain properties of proton heavy-nucleus interactions that are basic input material for a Monte Carlo model of the nuclear-electromagnetic cascade.

The apparatus that will be used to achieve these goals will consist of:

1. Several layers of CsI (Tl) each one radiation length thick.
2. Various configurations of tungsten, iron, and copper absorber interleaved with plastic scintillator sheets. Some or all of the scintillator sheets will consist of double wedges so that the sheet formed of two wedges is of constant thickness. (See Item 7 of the Appendix.)
3. A segmented (linear strip) probe of plastic scintillator.
4. A set of wire spark chambers for accurate definition of the lateral position of the beam particles.

The configurations of absorber material and scintillator probes will not be specified at this time. During the course of the measurements this configuration will be changed. This will make it possible to determine the overall devebpment of cascades in dense absorbers as well as (after rearrangement of the absorber and probes) particular properties of the cascades at particular absorber depths. It will not be possible to carry out all desired measurements with one single configuration since the cascade development can be influenced to some extent by the probes used to measure the charged component of the cascade.

With different arrangements, the following features of nuclear-electromagnetic cascades will be measured:

1. The longitudinal development of cascades.
2. The radial development of cascades.
3. Back scattering.
4. The transition effect for cascades passing from the primary absorber into the plastic scintillator ionization sampling layer. (See Ref. 5 of the Appendix.)
5. The accuracy of measurements of cascade lateral position using wedges of plastic scintillator. (See Ref. 7 of the Appendix.)
6. The amount of energy leaking out of the bottom of the spectrometer.
7. Mean values and fluctuations in various parameters (involving sampling layer signals) that might be used to measure primary energy.

8. The amount of primary energy that goes into the energy of charged nuclear evaporation fragments in proton-CsI interactions.
9. The charged particle multiplicity in proton-CsI interactions.
10. The cross section for inelastic interactions of protons with tungsten nuclei and with CsI nuclei.
11. The fraction K_{π^o} of the primary energy going into neutral pion production in individual interactions in CsI and in tungsten.

These measurements will be used to improve an existing Monte Carlo model of the nuclear-electromagnetic cascade. (See Item 3 in the Appendix.) This improved model will be used for design studies of the HEAO spectrometer and for ionization spectrometers in general.

The parameters which have the largest effects on the nuclear-electromagnetic cascade development are the inelastic cross section, multiplicity, inelasticity, and nuclear disintegration energy. Therefore, it is important to establish the mean values and fluctuations of these parameters. In order to do a good extrapolation to cosmic ray energies of the ionization spectrometer response determined at accelerator energies, one must know the dependence on primary energy of each of these parameters for interactions occurring in the absorber material finally used in the spectrometer.

Cross sections. We desire to measure the cross section for inelastic interactions of high energy hadrons with the target nuclei because this cross section is one of the basic parameters for determining the development of nuclear-electromagnetic cascades. It is important to know this cross section in order to make measurements of the cosmic ray flux and energy spectrum using ionization spectrometers having dense absorbers.

Inelastic cross section measurements are difficult to carry out with a single slab of target material, since it is not easy to obtain unambiguous definition of an interaction with counter techniques. However, if several targets are used in sequence, then the inelastic cross section can be derived from the distribution with depth into the target of the beginning points of cascades (i.e., the distribution with depth of interactions as defined by simple counter techniques), if care is taken to leave out of consideration those parts of the distribution which could be distorted by boundary effects. Now ionization spectrometers usually are constructed from several identical modules containing absorber and ionization detectors. Although the determination of the overall response of such an apparatus is the main object of the proposal, it should be possible to make these cross section measurements at the same time the spectrometer response is being determined. We propose to make such cross section measurements at the accelerator. The same method will be used to measure cross sections at 100-100,000 GeV with data obtained during the satellite flight of the apparatus.

Nuclear disintegration energy. Information about the nuclear disintegration energy can be obtained from interactions occurring in a CsI (Tl) section of the apparatus. This section will be located at the upstream end of the apparatus. This section will be comprised of several separate layers of CsI, each 1 radiation length in thickness. CsI (Tl) is sensitive to the disintegration energy, which appears in the form of charged fragments from nuclear evaporations. (Neutrons carry about one third of the disintegration energy.) Primarily, the charged fragments are heavily ionizing particles having very short path lengths in CsI (Tl). Therefore, one will be able to identify the layer of CsI (Tl) in which there occurs an interaction involving the emission of charged evaporation fragments. The output signal from that layer will be a measure of the nuclear disintegration energy for the interaction. In this way the dependence of the energy of nuclear disintegration on primary energy can be determined at the accelerator energies.

Multiplicity. The output signal from the CsI (Tl) layer immediately below the one in which an interaction occurs will provide information about the multiplicity of charged particles produced in the interaction. The variation of the multiplicity with energy will be obtained.

Inelasticity. It is difficult to make any unambiguous measurements of the inelasticity of the interactions with the apparatus planned. However, an estimate of the amount of energy appearing in neutral pions can be obtained by measuring the energy content of the electromagnetic component from the first interaction. This will be determined as a function of primary energy. Using charge independence one can from these measurements estimate the mean elasticity as a function of primary energy. Tungsten is a favorable material for these measurements because the radiation length of tungsten is small compared to the interaction length. In each event occurring in tungsten the electromagnetic cascade from the first interaction would tend to build up a maximum where the energy of this cascade can be reliably measured before one has interference from cascades arising from later interactions. Uncertainties in determining the location of the first interaction do not have a large effect on inelasticity measurements made using this method, unless the inelasticity is significantly dependent on the multiplicity of the interaction.

Conclusion. In this brief proposal we have only outlined the goals and general approach to the work proposed. The details of the experimental apparatus and the carrying out of this work at NAL will be developed later after the National Aeronautics and Space Administration (NASA) has taken action with respect to the larger HEAO collaboration (Ormes et al.) in which the authors are involved. A decision by NASA as to whether this collaboration will be supported is expected in July, 1970. If this decision is favorable to this collaboration, funding details for the work described in this proposal will be worked out soon thereafter. At that time the work outlined in this proposal can be better defined.

It would appear that the work described in this proposal would require 400 hrs or more of beam time (i.e., the equivalent of 2 calibration runs as described in the Bowen proposal attached).

The Appendix briefly describes related work with which the authors have been involved.

A P P E N D I X

Experience and Capabilities of LSU-MPI Groups

The authors of the present proposal either have been or are involved in the related work described below:

1. An experiment has been carried out that involved balloon flights of apparatus consisting of an ionization spectrometer, scintillation counters, spark chambers, and emulsions.[1-5] In this experiment it was possible to study the energy spectrum and charge composition of cosmic radiation in the 40-400 GeV energy interval.
2. The response of the apparatus described above has been determined using proton beams of 10, 20, and 30 GeV at the AGS in Brookhaven.[6,7]
3. Extensive Monte Carlo calculations which simulate the response of ionization spectrometers to protons have been carried out.[8-12] The model of the nuclear-electromagnetic cascade was first adjusted so as to give results which agree with the observations made in (2) above. The predictions of the model calculations also agree with measurements (burst size and lateral spread) made at a depth of 10 interaction lengths in the Kiel air shower experiment.[13]
4. The transition effect and the lateral distribution of the energy flow of electromagnetic cascades in assemblies having different critical energies has been investigated in an experiment which was carried out at Stanford.[14]

5. An ionization spectrometer at a mountain (cosmic ray) laboratory is in operation.[15] This spectrometer is unique in that it uses a glass-scintillator combination. The influence of the transition effect and low energy nuclear evaporation stars are minimized since the sampling material, plastic scintillator, is sufficiently similar to the absorber material, glass. Low Z material is used throughout.
6. Construction of spark chambers using optical and digitized readout systems has been accomplished successfully at MPI.[1-4,16] Optical spark chambers were used with the ionization spectrometer experiment described in Ref. 1-4 and in connection with an MPI experiment to measure solar neutrons.[16] Digitized spark chambers have been developed at MPI for a gamma ray experiment to be flown on the COS-B satellite. These are spark chambers of size 30 cm x 30 cm and having core readout. Presently a group from MPI is in Palestine, Texas, for balloon flights of a gamma ray experiment that uses these chambers.
7. The use of scintillator wedges to determine the axis of electromagnetic cascade showers has been investigated by the MPI group.[17]

The projects described above plus the past theoretical[18-22] and additional experimental[23] experience are the background on which we base our confidence that the program described in this proposal can be successfully carried out.

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